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DEVELOPMENT OF ULTRASONIC SCANNING SYSTEM FOR IN-PLACE INSPECTION OF BRAZED TUBE JOINTS

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Marshall Space Flight Center, Alabama

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16. Abstract

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The developed scan system is capable of scanning brazed tube joints, with limited clearance access, in 1/4- through 5/8-inch union, tee, elbow, and cross configurations. The average test time for a particular tube size and configuration, after a 30-minute setup sequence, is 3 to 4 minutes. The system is capable of detecting brazing defects as small as 0.008 by 0.010 inch which exceeds the 0.015-inch-diameter defect resolution required by specification.

The ultrasonic brazed tube scanner is recommended for any required evaluation of brazed tube joints which are within the scanner's dimensional capabilities. This recommendation is based upon the rapid inspection time and the capability of the basic ultrasonic method to detect defective conditions not associated with material density changes in addition to those which are dependent upon density variations.

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I. INTRODUCTION

This report presents the development of a prototype ultrasonic scanning system for nondestructive, in-place, nonimmersion testing of brazed joints in stainless steel tubing. The system was designed, developed, and built by the Quality and Reliability Assurance Laboratory, MSFC, especially for nondestructive testing (NDT) of tube joints on the Apollo Telescope Mount Thermal Conditioning System (ATM-TCS).

Ultrasonics was selected as the basic NDT technique because of its known response to discontinuities that are not associated with material density

changes. Discontinuities of this nature, such as cold braze and eccentric tube-sleeve relationship, are not detectable by radiography because of the absence of, or difficulty in, detecting density changes.

This report covers the following items:

a. Design of the brazed tube joint used on the ATM-TCS, along with typical occurring defects (their criticality and overall quality requirements per specification).

b. Stringent dimensional criteria and in-place access restrictions that established the physical configuration of the scanner head.

c. The resultant scanner head, recorder, controls, and overall system design.

d. Defect detection, recording, and interpretation data.

e. An evaluation of the system capability, both operationally and as regards defect detection.

II. DEVELOPMENT CRITERIA

A. Brazed Tube Joint Description

The brazed tube scanner was designed to ultrasonically inspect brazed joints in stainless steel tubing typical of those used on the ATM-TCS is manufactured by the Aeroquip Corporation and is shown in Figures 1 and 2. Prior to brazing, an 82-percent gold, 18-percent nickel alloy ring is inserted into the braze alloy recess. The tube which is to be brazed is then inserted into the sleeve, and the assembly is inductively heated to brazing temperature. The alloy ring melts and flows into the areas designated "A" and "B" (Fig. 2), creating a brazed joint. The brazed joint configurations used on the ATM-TCS are union, tee, elbow, and cross in both straight and reducing configurations.

B. Defect Types

Defects in the braze line between the sleeve and tube fall into two categories: those that present a density difference (on X-ray film) and those that do not. Ultrasonics is equally responsive to both categories. Some of the braze line defect conditions expected in this type joint were:

1. Lack of Braze (Tube and Sleeve Centerline Parallel and Relatively Concentric) — In this condition, the braze alloy has failed to flow out of the recess to completely cover the A and B area circumferences because of contamination, improper brazing schedule, etc. Normally, this condition presents a density difference on X-ray film.

2. Lack of Braze (Tube and Sleeve Eccentricity; e.g., Cocked Sleeve) — In this condition, the braze alloy has tried to flow into the A and B areas for a full 360 degrees but has been physically restricted because the braze gap was too thin at one point around the circumference. Hence, the braze line is correspondingly thicker, 180 degrees from this point, which does not present a density difference on the X-ray film when this condition is in line with the X-ray beam. Failure to detect this condition is highly probable with in-place radiography because of the physical restraints involved in multiple shots.

3. Cold Braze — In this condition, the braze alloy has flowed out into the A and B areas but has not bonded to either the tube or sleeve. Consequently, no density difference is shown on X-ray film, since the braze alloy is physically present.

C. Quality Requirements

The criticality of a defective area, and therefore the minimum defectiveness which can be allowed in a brazed joint, varies depending upon the number of defective areas, the location of the defective areas, and the axial length of the areas. An acceptable test method must be capable of accurately locating and sizing defective areas and must also have sufficient sensitivity to detect the maximum allowable defective area. The maximum allowable defectiveness of an Aeroquip brazed joint employed on the ATM-TCS (as stated in Aeroquip process standard A CES 403) is two defects in an axial line whose total axial length does not exceed 0.062 inch. The smaller of the two areas must exceed 0.015 inch axially to be rejectable. Therefore, the smallest single area which any test method must detect is 0.015 inch in diameter.

D. Design Criteria and Restrictions

As previously stated, this model of the ultrasonic brazed tube scanner was designed for the test and evaluation of brazed tube joints on the ATM-TCS. As a consequence, the overall dimensions of the scanner head were predicated by the sizes and configurations of the tube joints and the in-place accessibility to these joints on the finished assembly. Advance knowledge of the brazing process, i.e., which joints would be bench brazed and which would be in-place brazed, was not established at the time of the scanner head design. It was necessary, therefore, to design the scanner head to scan all of the joints which could possibly be brazed in place. The clearance requirements of the scanner head as gleaned from design drawings of the ATM-TCS are listed below and shown on Figure 3:

1. Top clearance, as measured from center line of joint — no requirement.

2. Bottom clearance, as measured from center line of joint — 1.340 inches.

3. Side clearance, as measured from center line of joint — 1.750 inches.

4. End clearance, as measured from sleeve edge — 1.250 inches.

The scanner head was dimensionally designed to accommodate straight and reducing union, tee, cross, and elbow joint configurations in 1/4-, 1/2-, and 5/8-inch diameters with the above clearance restrictions.

III. SYSTEM DESCRIPTION AND OPERATION

A. General

The scan system is shown in Figure 4. Figure 5 shows the relationship of the various major assemblies which are discussed in the following paragraphs.

B. Ultrasonic Technique

The ultrasonic technique employed is defined as loss-of-back reflection. Figure 6 shows the principles of this technique. High-frequency sound energy from the specially designed transducer is focused into the tube under test. The specially designed transducer is a focused type that utilizes a liquid-filled rubber boot to simulate an immersion test. The focused wave is transmitted through the contained and flexible (to accommodate contour changes) liquid volume into the tube joint and is reflected from the back surface of the tube. A loss of back reflections from the tube I.D. because of a discontinuity in the sound path is an indication of a defective brazed area.

C. Prototype Equipment

1. Scanner. The scanner head assembly (Fig. 4) provides the X-Y scan movement across the area under inspection. This is accomplished by rotating the transducer in a circumferential motion around the tube joint while traveling down the tube in a longitudinal direction, thus generating a continuous helix pattern. One circumferential revolution corresponds to one X-scan pass, and the travel down the tube is the Y-moveover or travel as in conventional X-Y scanning modes. The scanner was designed for a center-to-center distance between circumferential passes of 0.031 inch. Figures 7 and 8 present views of the scanner head assembly with designations of each part. Each major subassembly of the scanner is discussed in the following paragraphs.

a. Transmit-receiver assembly. Parts that comprise this assembly are:

(1) Transducer — 0.30-inch diameter, 0.36-inch length, sharply focussed.

(2) Transducer boot — The boot is a latex rubber balloon tip that is attached to the transducer by a brass sealing band. The boot contains an ultrasonic search wheel fluid which provides sound wave transfer and focusing media to simulate an immersion test. Flexibility is provided by the boot to conform to tube joint contour variations.

(3) Slip-ring assembly — Transmit-receive signals flow between the transducer and ultrasonic flaw detector by means of the slip-ring assembly. A contact ring and slip ring comprise the assembly that is electrically insulated from the case and lug. The contact ring is stationary and is electrically connected to the flaw detector. The slip ring rotates and is electronically connected to the transducer. As the slug rotates, continuous contact is maintained between the contact ring and slip ring. The transducer is grounded to the slug which completes the electrical circuit.

b. Drive mechanism. This assembly includes the scanner housing or case, motor, slug, and necessary mechanism to drive the slug at the design speed. The slug, which houses the transducer and boot, is rotated around the tube while it traverses the tube axially by means of the internal threads of the case. Limit switches prevent slug overtravel in either direction by reversing the mechanism. The total slug travel is 0.500 inch which will cover one joint end per scan.

c. Transmitter. The recorder transmitter is an integral part of the scanner head assembly. It is a servo unit that "tracks" rotation of the slug around the tube and synchronizes one slug revolution to one "X" pass of the recorder C-scan printout.

2. Recorder. The recorder is a prototype unit and is similar to other facsimile recorders in that it will provide a developed plan view (C-scan) of the braze line conditions. The prototype unit is different to the extent that the drum containing the helically wound print wire rotates continuously in one direction rather than reversing for each X-scan as in Y-moveover type scanning modes. Included in the recorder housing are the power supplies and related electronic components for the scanner head.

3. Recorder Accessory. The standard C-scan recording uses a dark background (continuous print). The defective indications are shown by an absence of print (white areas). With this type of recording, small indications are often missed because of a characteristic residue from the dark printing being deposited by the print bar over the white defective area indications. To overcome this adverse characteristic, a special recorder accessory, called the "dotter," was used with the system as shown in Figure 5. With the dotter, the recording background is a series of low-intensity (brown) dashes and defect indications print as dark (black) lines (Fig. 9.) The brown-dotted background prohibits the residue buildup associated with standard C-scan recordings and results in increased resoltuion.

D. Ultrasonic Equipment

The ultrasonic flaw detector used in the system development was the Budd Company Model 725 Immerscope with a 725 R1 Pulser Receiver and a FG-2 Flaw Gate.

E. Setup Procedure

The basic scanner head will accommodate tube joints from 1/4 to 3/4 inch in diameter. However, for each tube size, a front and rear alignment plate is required to position the joint under test in the center of the scanner head. Various configurations of the tube joints, such as tees, elbows, crosses, etc., can be successfully tested after the proper alignment plates are attached. Figure 10 shows the use of a front alignment plate designed for the testing of 1/4-inch tees, elbows, and crosses. To test a tube joint of a particular size and configuration, the proper alignment plates are selected and attached to the scanner head. The scanner head is then placed on a "standard" tube joint containing preplaced defects of known size, and a final adjustment of the alignment plates is accomplished to locate the joint in the center of the scanner head. The limit switches are adjusted to provide the required scan coverage; the transducer position is adjusted for proper focusing; and the ultrasonic instrument is peaked to indicate a defective condition. The scanner head can now accept and test tube joints of the same size as the "standard" joints.

IV. DEFECT INTERPRETATION

A. A-Scan Presentation

Viewing the A-scan (scope trace) is an effective means of evaluating a brazed tube joint. Not only can defective areas be easily detected and sized, but the location of the transducer on the brazed joint can be easily noted. Figure 11 shows the scope traces that occur during a typical joint revolution. It is evident from this figure that the axial location of the transducer is easily determined. Although the location of the transducer on the joint is an important factor in the joint evaluation, the major reason for the preference of the A-scan is the distinguishing of tube/sleeve eccentricities from small defective areas. A small defective area (less than 0.020 inch in diameter) will not intercept the full area of the ultrasonic beam and therefore can only be detected by a drop in amplitude of the back surface reflections. This drop in amplitude can be easily recorded, but variations in a braze line thickness may cause an amplitude drop of the same magnitude. Therefore, a small defective area cannot be distinguished from a braze thickness variation by a recorder, but the two conditions can be easily distinguished by the rate of the amplitude loss as viewed on the scope trace (A-scan). A defective area will cause the signal amplitude to change rapidly whereas an eccentricity condition results in slow-changing amplitude variations. Another advantage of the A-scan over the

C-scan is the detection of defective areas larger than 0.060 inch in diameter. Figure 12 shows the scope traces characteristic of large defects. When the transducer crosses the edge of the defective area, the back surface reflections drop out, resulting in a recordable condition. However, when the transducer comes fully on the defective area, a characteristic ringing of the sleeve thickness occurs that is not recordable. The result on the C-scan recording in this case would be a printout of the edges of the area which would accurately size the area if the center of the area was confirmed defective by viewing the A-scan.

B. C-Scan Presentation

The C-scan is an effective aid to the operator in determining size and location of the defective areas and may be required in certain applications for permanent record purposes. Because of the individual variations in tube joints previously mentioned, the C-scan should not be relied on for the detection of defective areas less than 0.020 inch in diameter. However, when the detection requirements are for defective areas 0.020 inch in diameter and larger, the C-scan is an accurate and valuable tool.

All C-scans produced, regardless of tube size or configuration, will have basic similarities. Figure 9a is a C-scan recording of a 1/2-inch-diameter joint which contained no defects. The untreated recording, as shown, is difficult to interpret because of the visual influence of the hump area. Figure 9b is the above-mentioned C-scan with a specially designed template overlayed on the recording. Figure 9c is a later C-scan of the same tube joint after the addition of an 0.040- and 0.020-inch-diameter simulated defects.

V. SYSTEM EVALUATION AND CAPABILITY

A. General

The evaluation of the scan system was concerned with both the operational characteristics and the defect detection capabilities of the system. The system was evaluated for ease of operation, scan times, and joint configuration adaptability in addition to defect detection capabilities. The location and size determinations of detected defects were confirmed with metallographic examination.

B. Operational Capabilities

During this phase of the evaluation, three joint configurations (tee, elbow, and straight union) of 1/4- and 1/2-inch diameters were used to judge the operational capabilities and to determine the setup and scan times for the various configurations and sizes.

The scanner head was first aligned on a 1/2-inch-diameter straight union joint containing 0.020- and 0.040-inch-diameter preplaced defects. These defects were located in the center of the "A" area on one side of the union. Fifteen scans were made on the joint end with the defective area. The defective areas (0.020 and 0.040 inch in diameter) were detected on all 15 scans. The scanner head was then placed on the opposite end of the union, and 15 scans were obtained on this joint. No defective areas were apparent. An average scan time of 3-1/4 minutes was recorded for one scan of a union end.

The front alignment plate was replaced with a 1/2-inch tee and elbow adaptor, and one tee and one elbow were scanned. Five minutes were required to change out the alignment plate, and an average of 4 minutes was required to scan each joint of the tee and elbow. This average time included the repositioning of the scanner head on each joint end.

The same tests detailed above for the 1/2-inch-diameter joints were repeated on 1/4-inch joints of the same configurations. The following conclusions were reached as a result of these tests:

1. An average time of 30 minutes is required to adapt the scanner head from one joint size to another.

2. An average scan time of 3 to 4 minutes is required to scan one end of a joint.

3. An average time of 5 minutes is required to adapt the scanner head for elbow and tee testing from straight unions of the same size.

4. Test results were 100-percent repeatable so far as the detection of 0.020-inch diameter and larger defects are concerned.

C. Defect Detection Capabilities

The evaluation of the system's defect detection capabilities was performed on 37-1/4- and 13-1/2-inch-diameter joints in elbow, tee, and straight union joints. All defective joints were metallographically examined to confirm the detection and to determine sizing accuracy. The system was calibrated on the standard joint containing 0.020- and 0.040-inch-diameter preplaced defects, and each joint was scanned a minimum of twice. A total of six naturally occurring defects (voids) involving 5 of the 50 joints was detected. The locations of the defects were determined by stopping the scan head when the scope trace indicated that the transducer was directly above the defect and by a physical measurement taken from the C-scan. The location of the defective areas was the same with both methods and there was no measurable error in the axial or circumferential location of any area. The sizes of the defects were determined from the A-scan by comparing the time of signal influence per circumferential scans (defect width) and number of circumferential scans (defect length) that the signal was affected, with the effect on the signals by a standard defect. The size determination from the C-scan was made from a direct measurement on the recording. Table 1 lists the size of the six defective areas as determined by both methods and the actual size of the areas as obtained from a metallographic examination. Figures 13, 14, and 15 are typical examples of the metallographic evidence of defective conditions and the corresponding C-scan recordings.

TABLE 1. DEFECT SIZE COMPARISON

	A Scan		C Scan		Actual	
Defect	Width[a]	Length[b]	Width	Length	Width	Length
1	0.015	0.060	0.015	0.040	0.013	0.060
2	0.030	0.125	0.020	0.125	0.020	0.125
3	0.020	0.020	0.010	0.020	0.010	0.030
4	0.015	0.015	0.010	0.020	0.010	0.015
5	0.010	0.010	0.010	0.020	0.008	0.010
6	0.010	0.010	Not Recorded		0.015	0.015
Maximum error	0.010	0.010	0.002	0.020		

a. The "X" dimension in inches as measured circumferentially

b. The "Y" dimension in inches as measured axially

A total of five ultrasonically "clean" A and B areas were cross-sectioned in 0. 020-inch increments. No defective areas were located by this examination.

It was concluded that the detection and location of defective areas 0. 010 by 0. 010 inch and larger could be accurately determined from both the A-scan and the C-scan. For an accurate determination of the size of the defective area, both the A-scan and the C-scan presentations are required. The A-scan is more accurate than the C-scan in determining the length of the defective area while the C-scan is more accurate in determining the width. Although the maximum width sizing error by C-scan as shown in Table 1 is 0. 002 inch, a more repeatable increment of resolution from the recording is 0. 005 inch. Of the six natural occurring defects which were detected, there was a maximum error in length sizing of 0. 010 inch with the A-scan presentation (defect 6). The error in this case is half of the difference between the two "standard" defects of 0. 040 and 0. 020 inch. This is the maximum error that would occur because the operator can more easily make a comparison discrimination when the actual defect size falls closer to either the 0. 040- or 0. 020-inch standard defect, in which case the error would be less than 0. 010 inch. By decreasing the range of "standard" defect sizes from 0. 020- to 0. 010-inch increments, then the expected maximum length sizing error by A-scan interpretation could be reduced to 0. 005 inch.

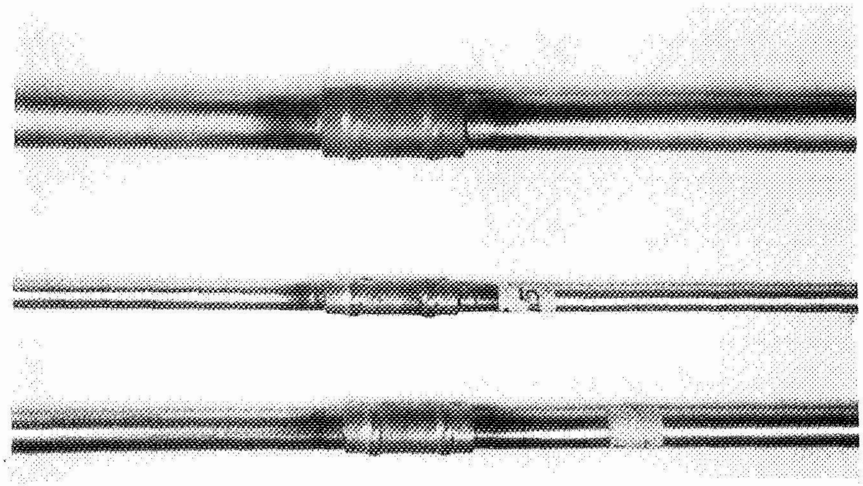
VI. CONCLUSIONS AND RECOMMENDATIONS

The ultrasonic brazed tube scanner was shown to be a reliable, accurate, and diversified brazed tube inspection system. The system was demonstrated capable of scanning 1/4- through 5/8-inch-diameter brazed joints, with limited side, bottom, and access clearances in union, tee, elbow, and cross configurations. The joint scan time of 3 to 4 minutes coupled with the maximum setup time of 30 minutes gives this system a clear inspection time advantage over other methods. Tests performed on tube joints containing preplaced defects confirmed the ability of the test method to reliably detect defects 0. 020 inch in diameter and larger. The smallest natural-occurring defect which was detected measured 0. 008 by 0. 010 inch. The size and location of all detected defects were confirmed by a metallographic examination and metallographic sampling examinations of ultrasonically clean areas revealed no nondetected defects. Both the A- and C-scan presentation methods were reliable in detecting and were accurate in locating the defective areas.

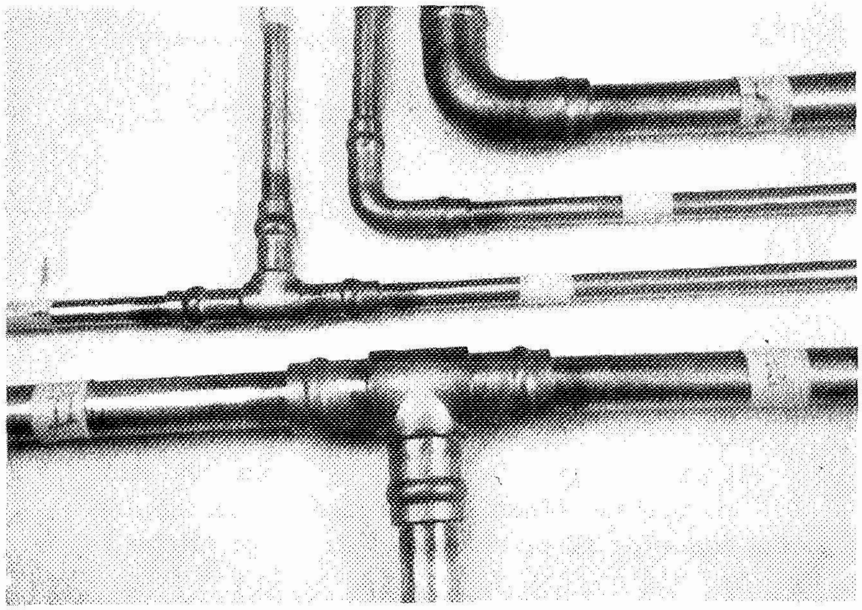
To accurately size a defective area, both A- and C-scan presentations are required. The C-scan measurements of defect width was within 0.002 inch of the actual dimension as measured metallographically. The maximum error in the defect length determination by A-scan is essentially limited by the size range of the standard defects and can be effectively reduced by reducing the standard defect size incremental differences.

The ultrasonic brazed tube scanner is recommended for the evaluation of all brazed tube joints that are within its dimensional capabilities and for which an inspection is desired. This recommendation is based upon the in-place scanning and the rapid inspection time capabilities of the system and the innate ability of ultrasonic test methods to detect defects which are not related to material density changes.

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama, July 15, 1970
965-21-01-0300

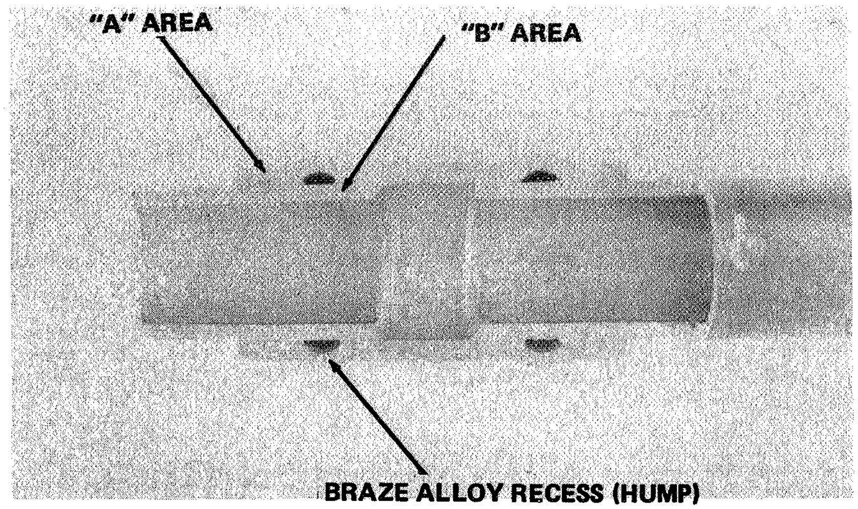


3/8-, 1/4-, AND 1/2-INCH UNIONS



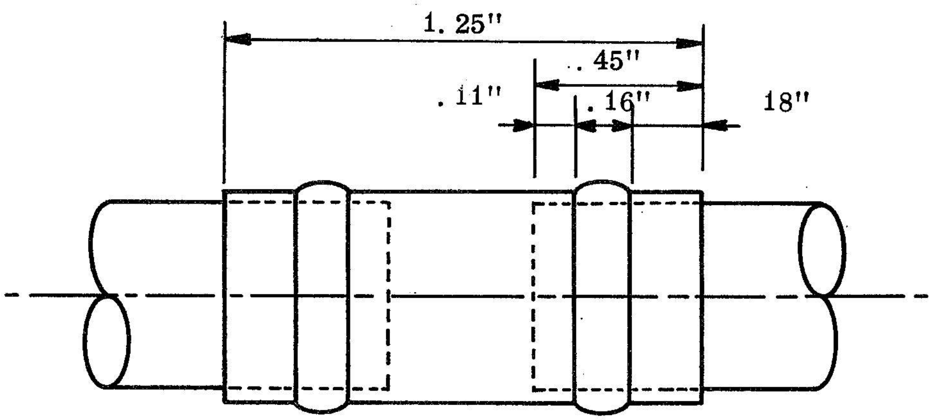
1/2- AND 1/4-INCH TEE AND 90-DEGREE ELBOW JOINTS

Figure 1. Aeroquip tube joints (typical of those used on the ATM-TCS).



CROSS-SECTION OF 1/2-INCH TUBE JOINT

(Approximately 1.6X)



UNION JOINT. (Overall lengths are the same for all size unions. "A" area, "B" area, and hump axial dimensions are average values and are the same for all sizes and joint configurations.)

Figure 2. Construction details of aeroquip brazed joint.

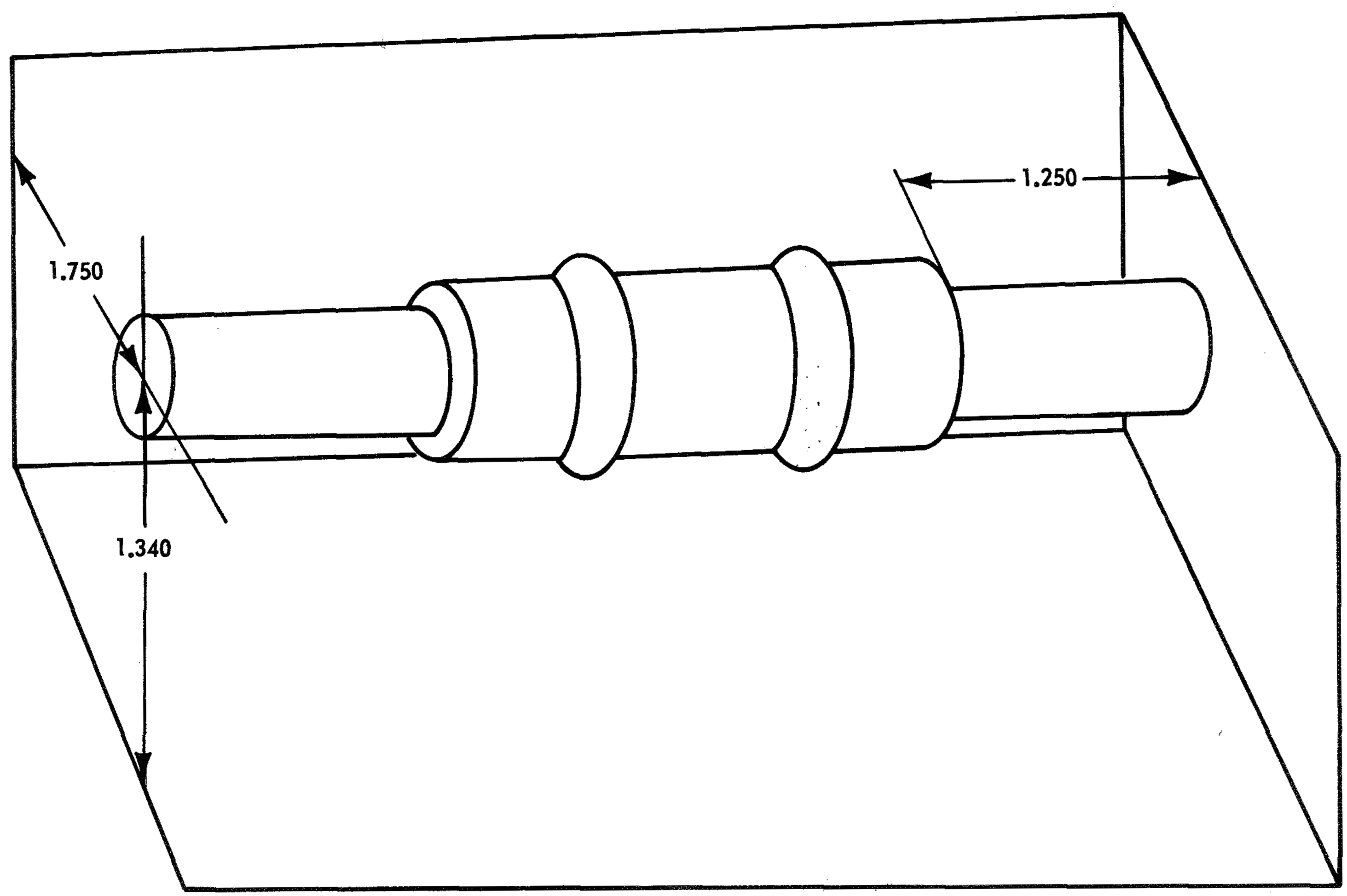


Figure 3. Tube joint access restrictions.

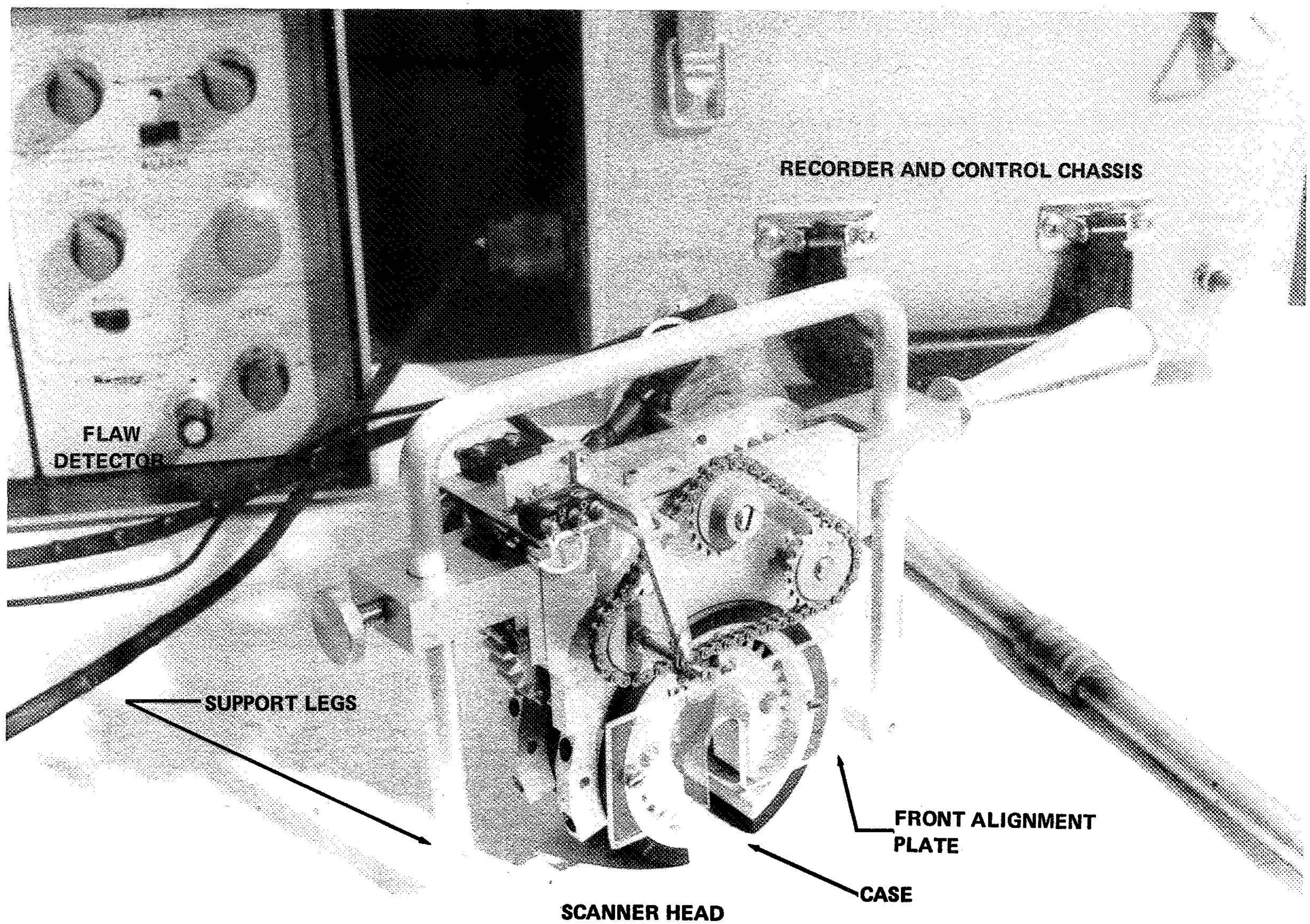


Figure 4. Prototype Scanning System.

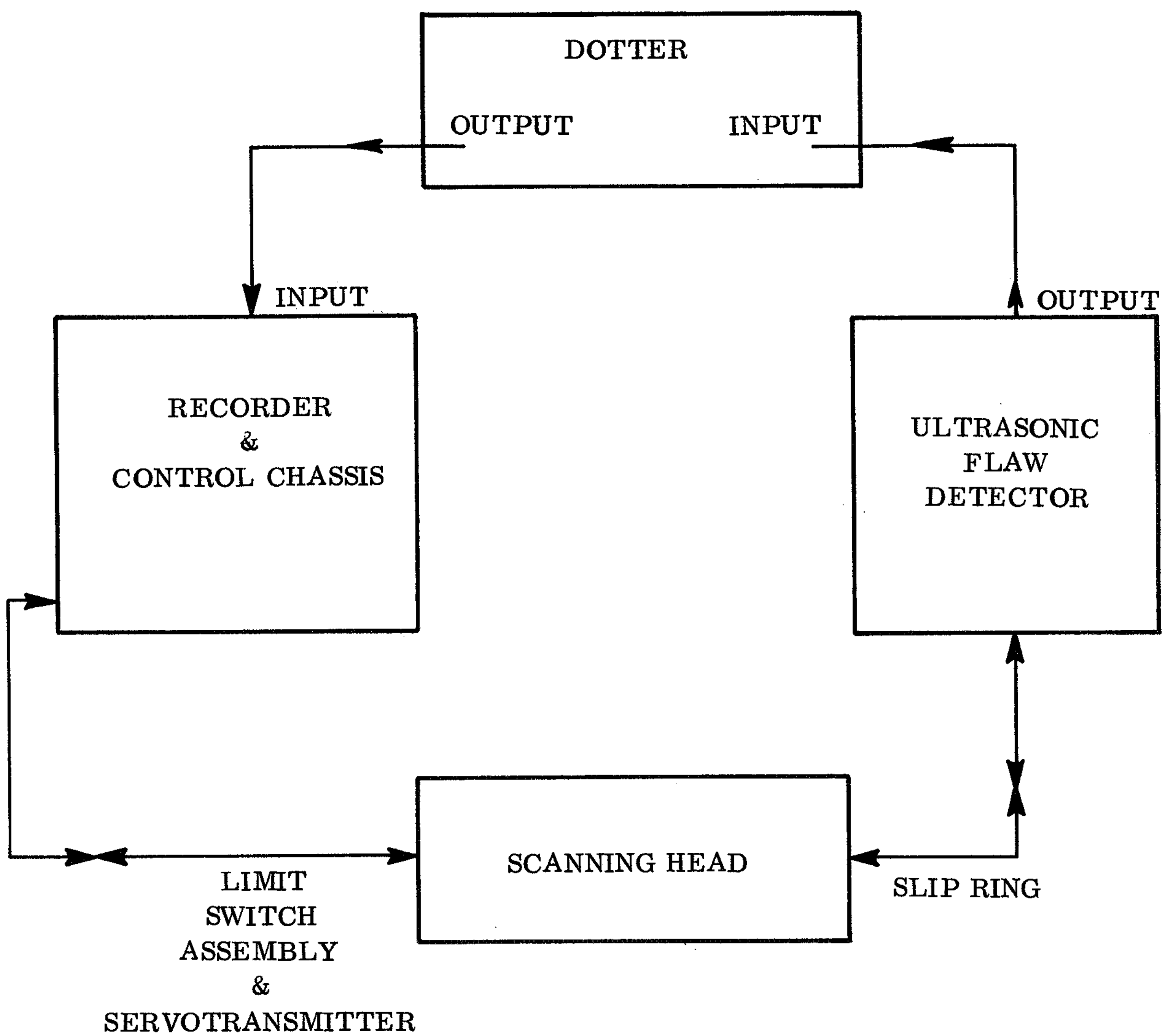
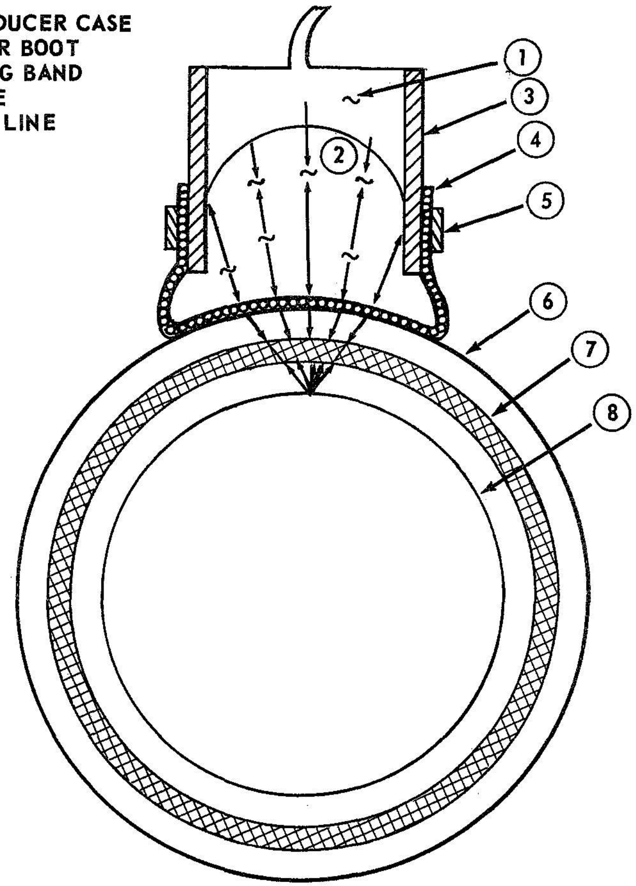
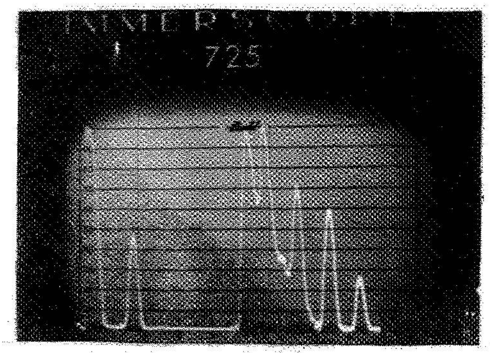


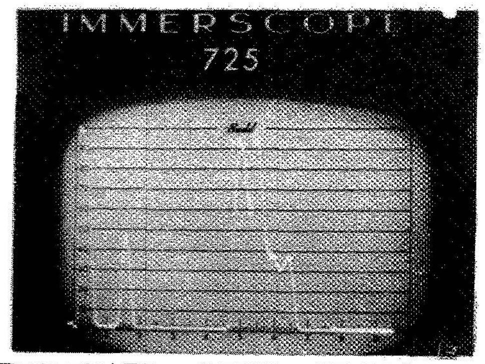
Figure 5. Prototype Scan System block diagram.

1. TRANSDUCER, 10 Mc, 0.3" FOCAL LENGTH
2. ULTRASONIC SEARCH WHEEL FLUID
3. TRANSDUCER CASE
4. RUBBER BOOT
5. SEALING BAND
6. SLEEVE
7. BRAZE LINE
8. TUBE





GOOD BRAZE — GOOD BRAZE IS INDICATED BY THE RESOLUTION OF THE BACK SURFACE OF THE TUBE. SIGNAL FROM 0 TO 2 (SCOPE SCALE) IS THE MAIN BANG. SIGNAL FROM 4.8 TO 6.0 INDICATES SOUND WAVE REFLECTIONS FROM THE RUBBER BOOT SLEEVE INTERFACE. SIGNALS AT 6.5, 7.5, AND 8.25 ARE REFLECTIONS FROM THE BACK OF THE TUBE.



DEFECTIVE BRAZE — DEFECTIVE BRAZE WILL BLOCK THE SOUND WAVE AT THE DEFECTIVE AREA RESULTING IN NO REFLECTIONS, OR VERY WEAK ONES, FROM THE BACK OF THE TUBE.

Figure 6. Ultrasonic geometric characteristics with representative scope traces of good and bad braze.

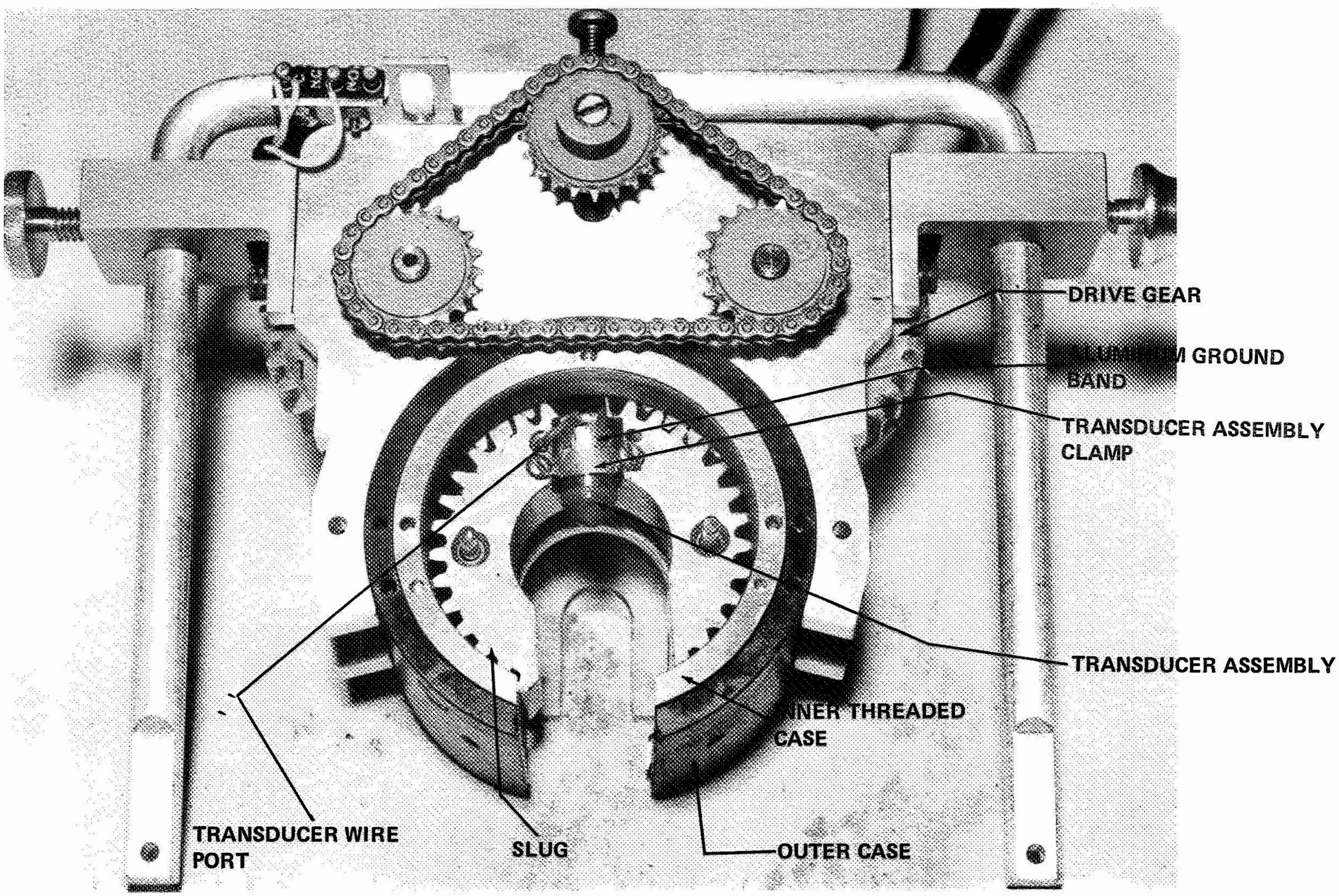


Figure 7. Prototype scanner head, front view excluding alignment plate and limit switch contact arm.

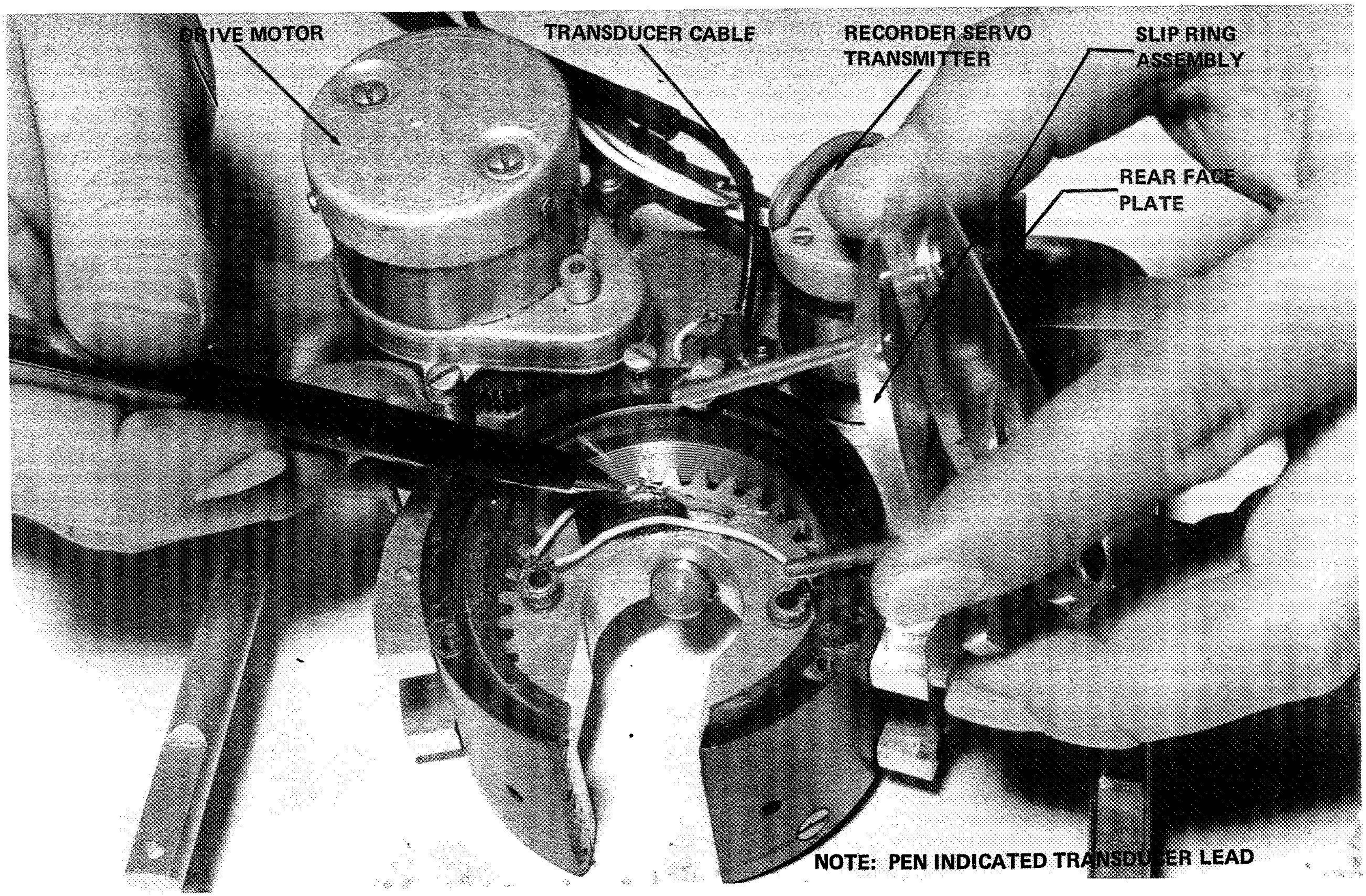
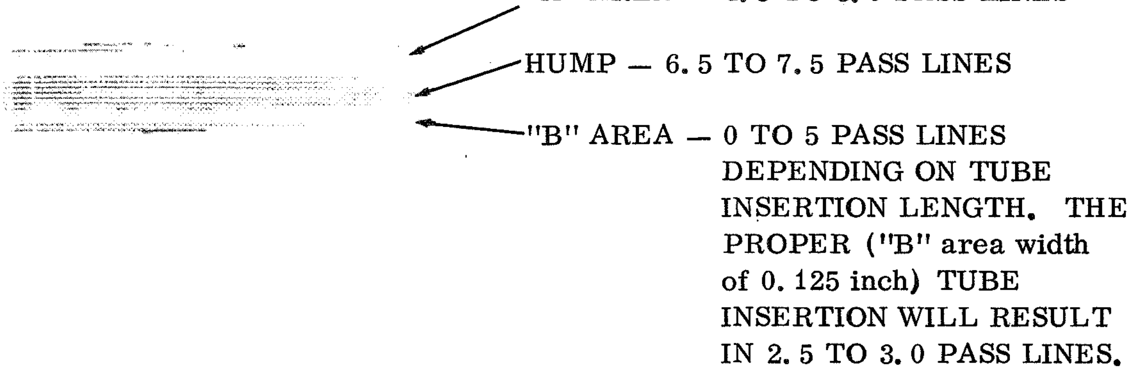
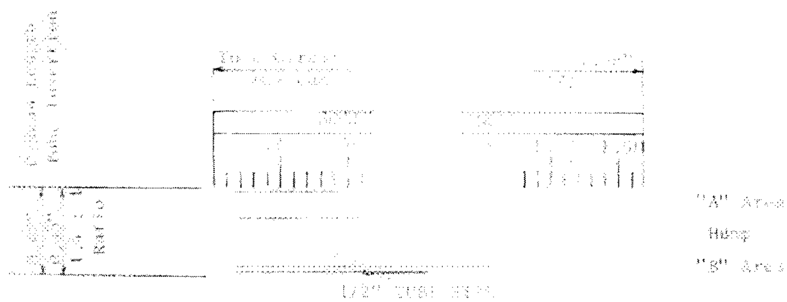


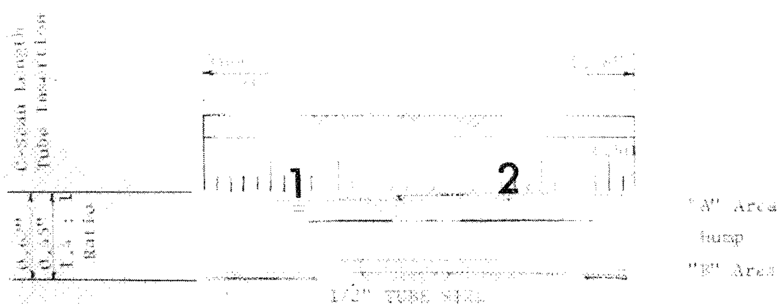
Figure 8. Prototype scanner head, rear view with slip ring, contact ring, and rear alignment plate unfastened.



a. C-scan of 1/2-inch-diameter tube joint with no defective areas



b. Above C-scan with defect overlay template superimposed



1. 0.040-INCH DIAMETER HOLE
2. 0.020-INCH DIAMETER HOLE

c. C-scan of above joint with 0.020- and 0.040-inch-diameter simulated defects

Figure 9. C-scans of 1/2-inch-diameter brazed joint.

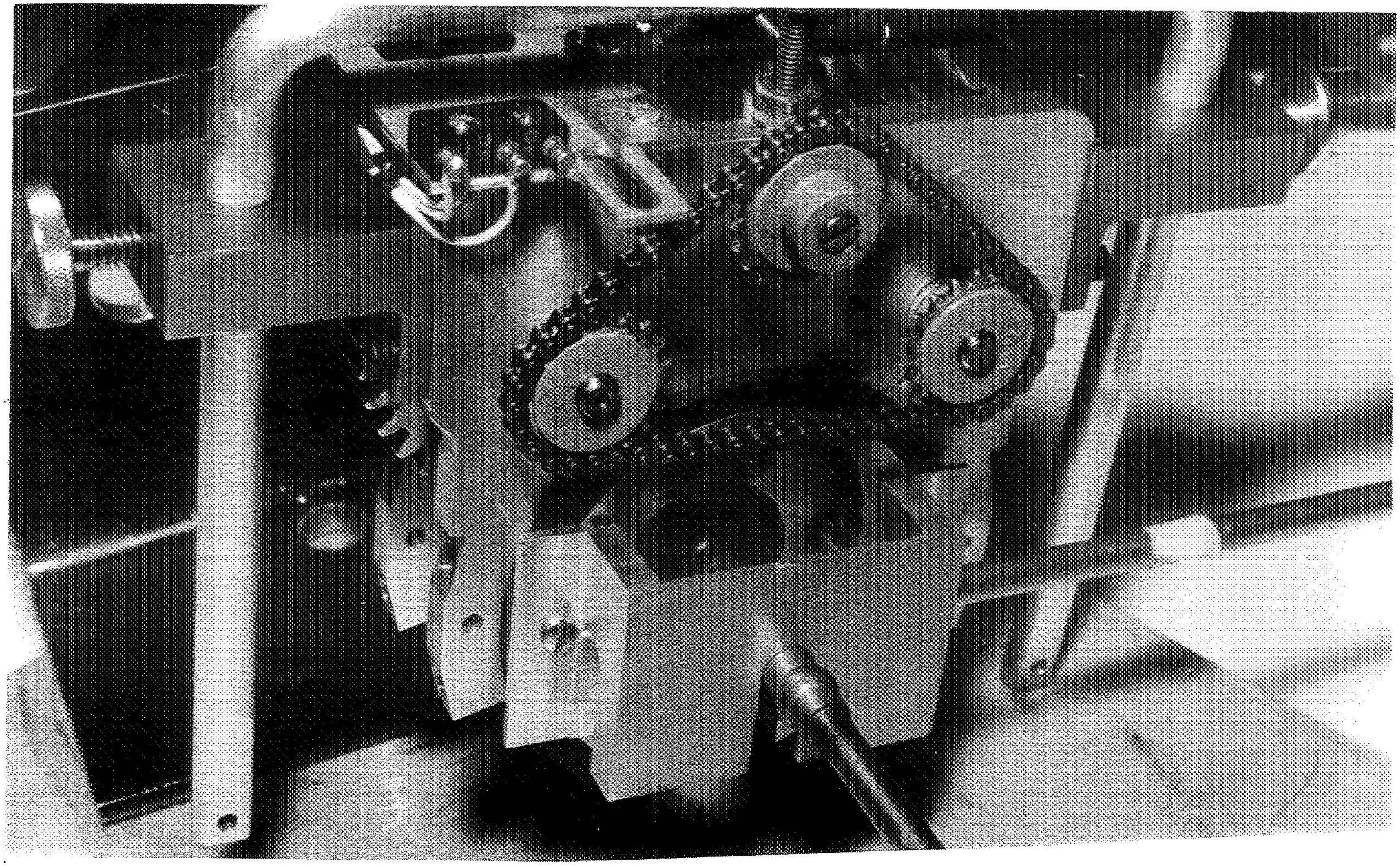
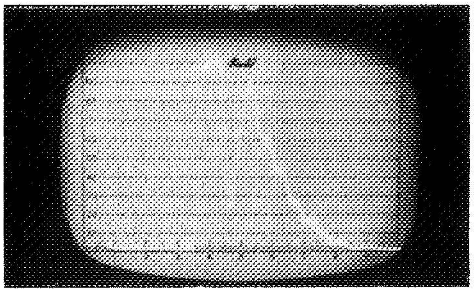
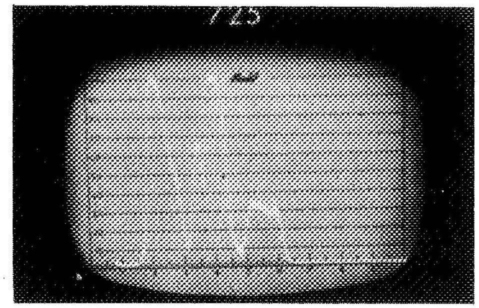


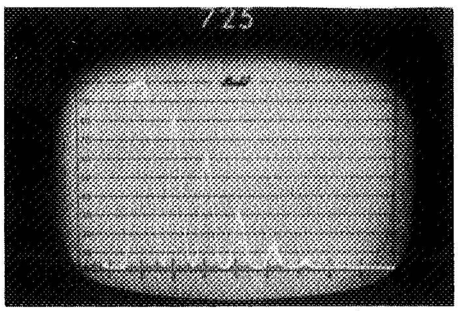
Figure 10. Prototype scanner head with 1/4-inch tube tee and elbow front alignment plate.



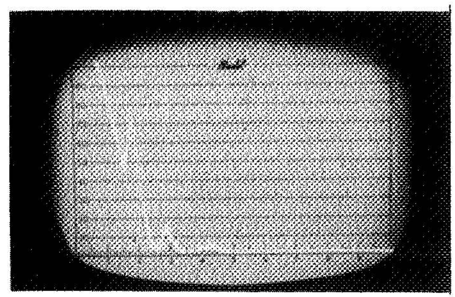
a. Transducer off of sleeve-on tube. (Characterized by the tube ringing pattern; 5. 5 on scope trace.)



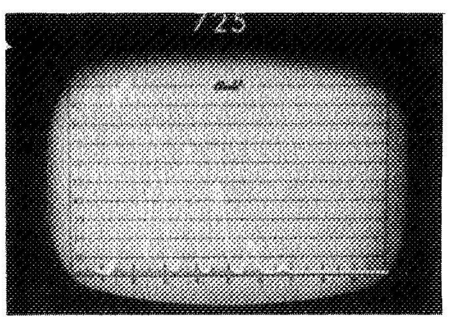
b. Transducer starting onto sleeve. (The tube reflections decrease and the sleeve top surface reflection starts to occur; 1. 5 on scope trace.)



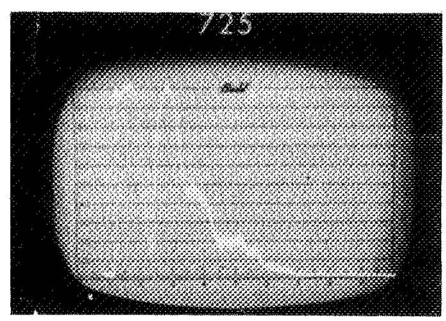
c. Good Braze "A" area. (Characterized by strong back surface reflections at 3, 4, and 5 on the scope trace. This trace will occur for 5 revolutions.)



d. Transducer on hump. (Characterized by slow shift to the left of the scope trace. Coming off of the hump, the trace returns to the right.)

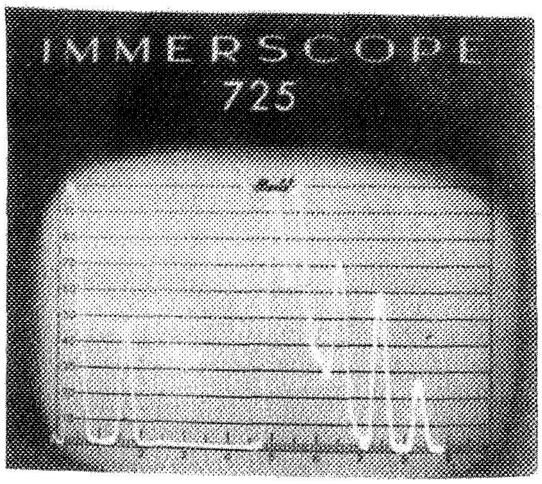


e. Good braze "B" area. (The same trace as good braze on "A" area. This trace will occur for 2. 5 to 3. 0 revolutions, if the tube insertion length is proper.)

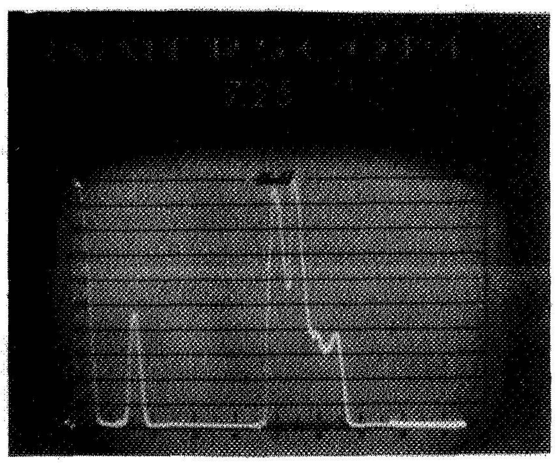


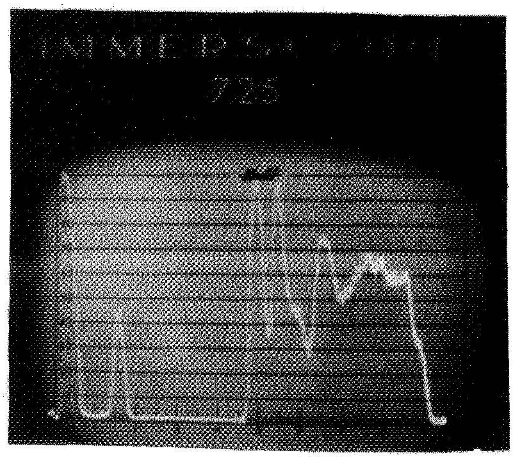
f. Transducer on sleeve past the "B" area. (Same trace as for the transducer on the tube, Figure 11a, except that there will be a start time difference in the trace.)

Figure 11. Flaw detector scope trace patterns.



a. Scope trace indicative of good braze

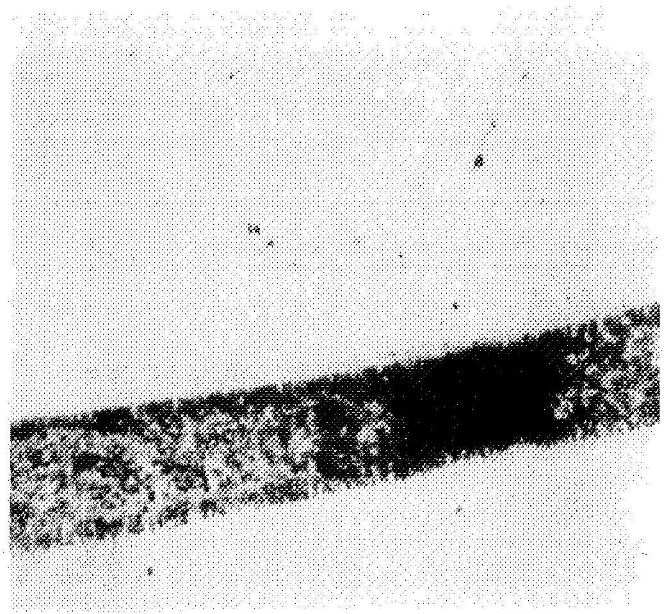




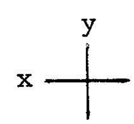
b. Defective area. (Note that the back surface reflections are completely blocked. A defect will cause the back reflections to drop out very quickly. They will return as abruptly when the defective area is crossed.)

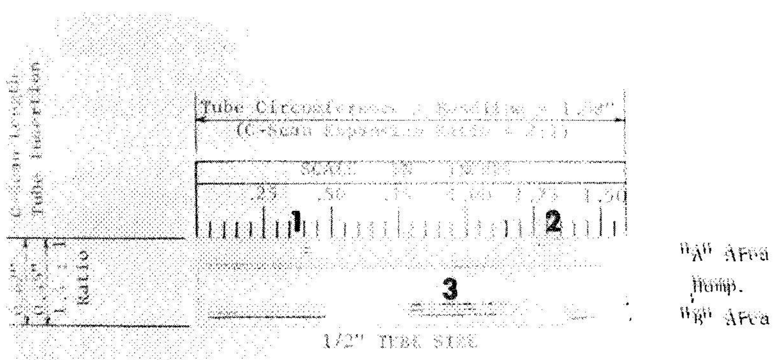
c. Ringing pattern characteristic of defective areas larger than 0.060 inch in both X and Y dimensions

Figure 12. Scope patterns characteristic of defective areas.



METALLOGRAPHIC CROSS-SECTION OF DEFECT FOUND IN "A" AREA
(Defect size: x-dimension varied from 10 to 13 mils;
y-dimension-60 mils. Magnification: 60X.)

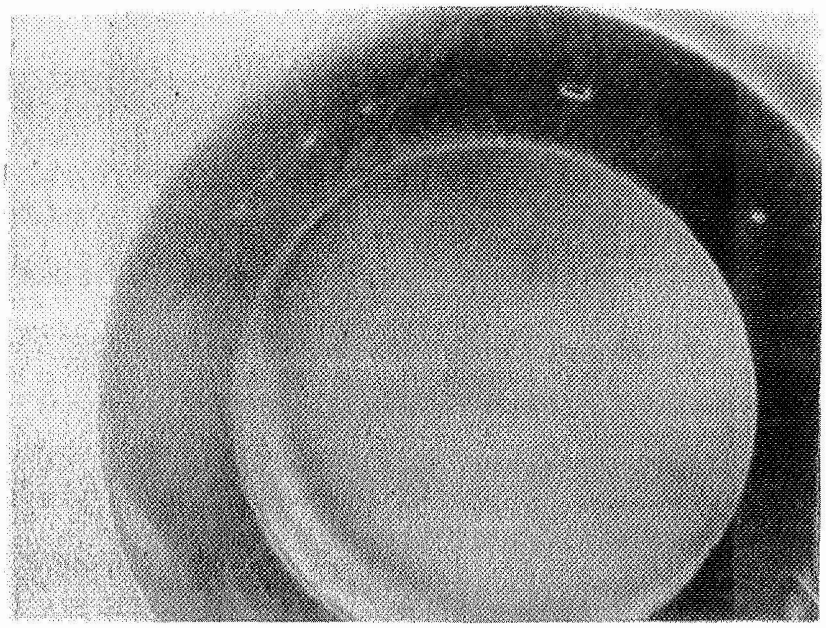




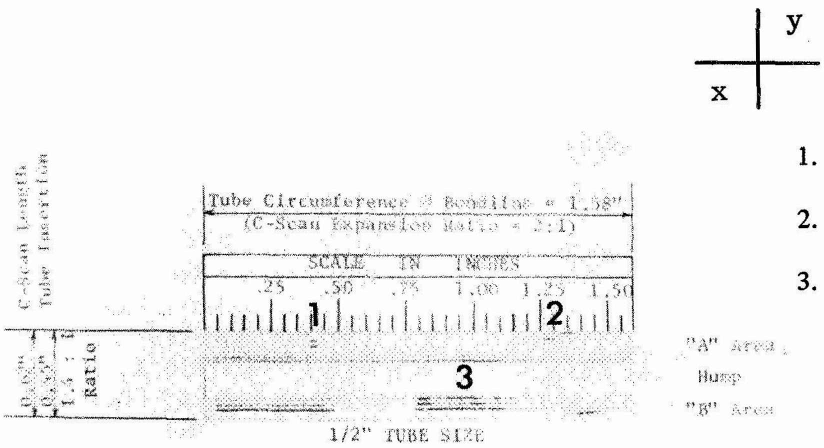
1. DEFECTIVE AREA SHOWN ABOVE (defect 1, Table 1).
2. DEFECT IN SLEEVE MATERIAL.
3. "B" AREA DEFECTS (see Figure 14).

C-SCAN OF ABOVE DEFECT WITH TEMPLATE OVERLAY (0.7X)

Figure 13. C-scan and cross-section of 1/2-inch-diameter tube joint with natural voids.



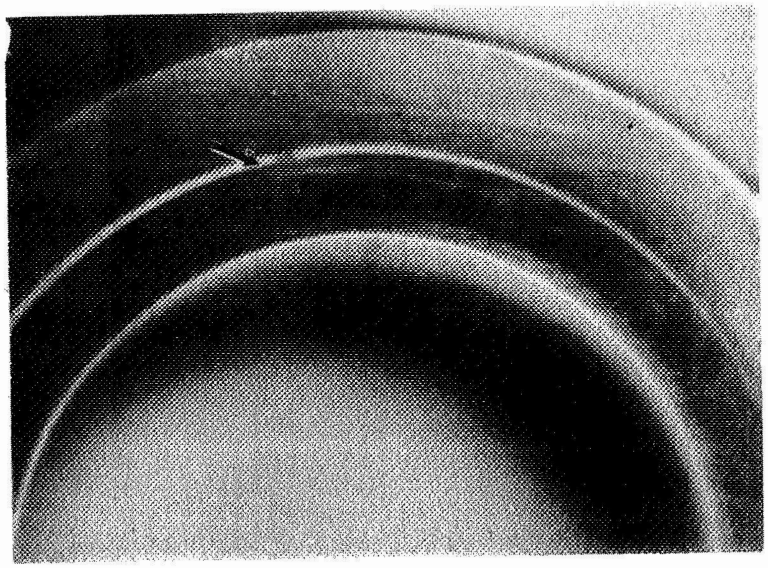
METALLOGRAPHIC CROSS-SECTION OF VOID FOUND IN "B" AREA
(Defect size: x-dimension varied from 5 to 20 mils;
y-dimension traversed the entire "B" area. Magnificaion: 7X.)



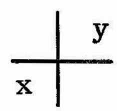
1. "A" AREA DEFECT (see Figure 13).
2. DEFECT IN SLEEVE MATERIAL.
3. DEFECTIVE AREA SHOWS ABOVE (defect 2, Table 1).

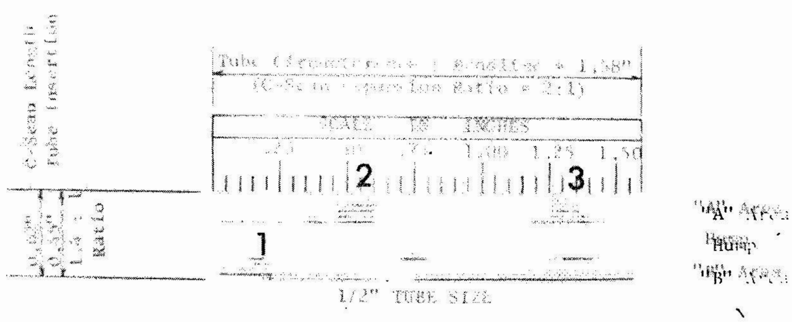
C-SCAN OF ABOVE DEFECT WITH TEMPLATE OVERLAY (0.7X)

Figure 14. C-scan and cross-section of large void in 1/2-inch diameter tube joint.



METALLOGRAPHIC CROSS-SECTION OF NATURAL VOID FOUND IN "B" AREA
(Defect size: x-dimension varied from 5 to 10 mils;
y-dimension-30 mils. Magnification: 10X.)





1. DEFECTIVE AREA SHOWN ABOVE (defect 3, Table 1).
2. 0.060-INCH SIMULATED DEFECT.
3. 0.060-INCH SIMULATED DEFECT.

C-SCAN OF ABOVE DEFECT WITH TEMPLATE OVERLAY (0.7X)

Figure 15. C-scan and cross-section of 1/2-inch-diameter tube standard with simulated and natural voids.

APPROVAL

DEVELOPMENT OF ULTRASONIC SCANNING SYSTEM FOR IN-PLACE INSPECTION OF BRAZED TUBE JOINTS

By J. L. Haynes, C. G. Wages, and H. S. Haralson

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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